



## **RESEARCH DEPARTMENT**

### **THE APPLICATION OF CORRELATION METHODS AND PHASE-COHERENT DETECTION TO ROOM ACOUSTICS**

**Report No. B-062**

**( 1955/19 )**

**THE BRITISH BROADCASTING CORPORATION  
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Section	Title	Page
	SUMMARY . . . . .	1
1	INTRODUCTION . . . . .	1
2	THE DEVELOPMENT OF THE PHASE-COHERENT PULSED GLIDE . . . . .	2
	2.1. Experimental Chain . . . . .	3
	2.2. Description of the Instrument . . . . .	4
	2.3. Details of the Experimental Method . . . . .	5
3	EXPERIMENTAL WORK AND RESULTS . . . . .	6
	3.1. Investigations in Rooms . . . . .	6
	3.2. Some Theoretical Considerations in Connection with Small Rooms . . . . .	8
	3.3. Coherent Glides of Electrical Networks . . . . .	9
4	METHODS INVOLVING AUTO- AND CROSS-CORRELATION . . . . .	12
	4.1. Cross-correlation Methods . . . . .	13
	4.2. Coherent Glide between two Points in a Studio . . . . .	14
5	CONCLUSIONS . . . . .	15
6	REFERENCES . . . . .	15

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### SUMMARY

In an attempt to produce an improved method of displaying the acoustic behaviour of a room, an investigation has been made into some phase-sensitive and correlation methods. In particular, a phase-coherent modification of the pulsed glide type of display has been developed, in which the microphone output is modulated by the original frequency of excitation before being applied to the cathode ray oscilloscope. Tests made using this new instrument are described, and the results discussed. Correlation methods are also discussed, and the results of some tests involving cross-correlation are given. Finally, a modification of the phase-coherent pulsed glide, also making use of cross-correlation, is described.

### 1. INTRODUCTION.

In the investigation of the acoustics of a studio it is very desirable to be able to obtain a record of its behaviour which shows clearly the "singularities" in its frequency response. These may take the form of long "rings" at certain frequencies or they may be frequencies at which a greater or lesser degree of "colouration" is noticeable on speech from the studio. These effects, which are found more frequently in small studios than in large ones, often appear to be due to isolated normal modes of a fairly simple type and hence vary to a certain extent with position in the studio. However, it would appear that the total number and severity of these irregularities might provide a criterion of goodness for the studio and, certainly, a knowledge of their frequencies is of great importance in understanding its behaviour.

In order to obtain a permanent record of the transient frequency response of the studio, the "Pulsed Glide" type of display<sup>1</sup> was developed, and this has proved a very useful method of diagnosis. In this type of display colouration frequencies, when due to isolated modes, are generally shown as a straightening of the individual decay traces, due to lack of beats with neighbouring modes. Unfortunately, this feature is not always apparent without careful inspection of the display, particularly where there is no appreciable simultaneous lengthening of the reverberation time. Because of this difficulty it was decided to investigate a phase-sensitive method of display.

It is necessary to emphasise at this point that the work described in this report is not concerned with the statistical features of the pulsed glide display which are used in the measurement of diffusion<sup>2</sup> but only with the examination of frequency singularities. The general observations and conclusions on the relative values of the techniques referred to below apply only to this specific application.

Changes of pitch always occur during the decay of sound for frequencies on either side of a modal frequency, and pitch changes are also associated with structural resonances. These pitch changes may be recognized by the ear as colourations, if sufficiently prominent, and constitute an undesirable feature of the acoustics of a studio. In the type of display to be described first, the product of the amplitudes of the decaying sound and of the exciting frequency is shown on a logarithmic scale, and this method clearly indicates pitch changes whether these are due to structural resonances or isolated modes.

As with the normal pulsed glide, small studios give more comprehensible patterns than large ones; difficulties arise with large studios because of the extremely rapid variation of response with frequency. Also, because the longer reverberation time necessitates a slower pulsing rate, further information is lost unless an extremely slow glide is adopted. In general, this is limited by the stability of the tone source.

A shortcoming of the pulsed-glide type of display is the fact that the display changes completely as the microphone is moved from one position in the room to another. These changes are inevitable since they correspond to real changes in the contributions of the various standing wave systems, but since the object of any diagnostic method must be to indicate those features which are most generally encountered in the room, satisfactory information can be obtained only if displays from a large number of microphone positions are available for examination. The possibility of combining or correlating the outputs of two or more microphones distributed about the room was therefore explored; most possible methods were rejected, but a variation of the coherent detection display, described in Section 4, has some useful features.

## 2. THE DEVELOPMENT OF THE PHASE-COHERENT PULSED GLIDE.

The principle of the method to be described may be illustrated by considering the simple case of the sound decay taking place at a single frequency close to the original exciting frequency.

Here the sound decay may be represented by

$$A e^{-\alpha t} \cos \{ (\omega + \delta) t + \phi \}$$

If this is multiplied by the time function of the original tone,  $\cos \omega t$ , we obtain the expression:

$$\frac{1}{2} A e^{-\alpha t} [ \cos \{ (2\omega + \phi) t + \phi \} + \cos(\delta t + \phi) ]$$

The second term in the above expression may be selected by a low-pass filter arranged to remove frequencies greater than say, 10 c/s. The output then takes

the form of an exponentially decaying sine-wave of a frequency equal to the pitch change in the room. When there is no pitch change a real exponential is obtained, whose magnitude and sign depend on the phase of the voltage produced by the microphone.

A conventional ring modulator has been used to achieve the multiplication, and the instrument accordingly responds to odd harmonics of the original frequency in addition to the desired fundamental. It is not possible to use filters in the microphone circuit because of the phase shifts which would be introduced, but no trouble from harmonics has been experienced in practice.

It is convenient to convert the decays from a linear to a decibel scale, and this logarithmic conversion may be carried out either before or after the multiplication by the original tone. It is very much simpler from an instrumental point of view to pass the returning sound through a logarithmic amplifier before multiplication, but there are theoretical objections, and it has been found in practice that clearer displays more in accordance with prediction are obtained by reversing the order. Another disadvantage of logarithmic conversion before mixing is that this causes the instrument to respond also to odd sub-harmonics of the original frequency, if these are present in the returning sound. It will be appreciated that, apart from the above considerations, the instrument is virtually insensitive to noise, having an extremely small effective bandwidth.

### 2.1. Experimental Chain.

A block schematic diagram showing the normal interconnection of apparatus is given in Fig. 1. It will be seen that the chain is similar to that used for the conventional pulsed glide type of display, except that the coherent detector is substituted for the logarithmic amplifier and filters. Also, since it is necessary to provide an input of tone to the coherent detector at as high a level as possible, it is desirable to include an attenuator between the tone source and the tone pulser, to avoid overloading of the latter. The tone source output may then be 20 dB above "zero" level. (1 mW into  $600\Omega$ .)

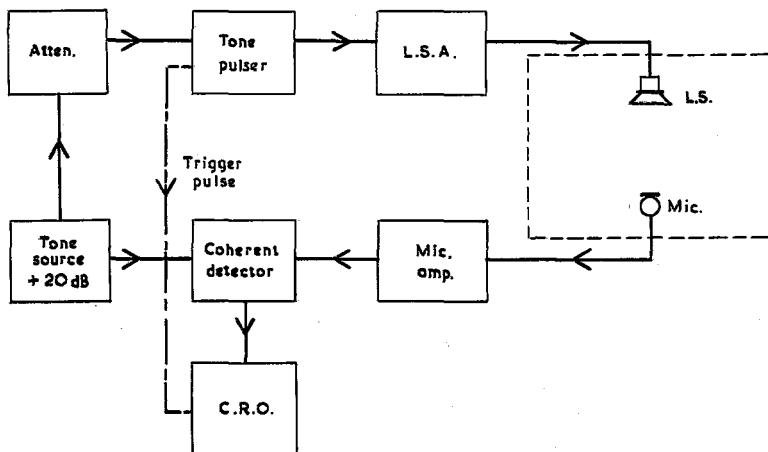


Fig. 1 - Block schematic diagram of coherent detector chain.

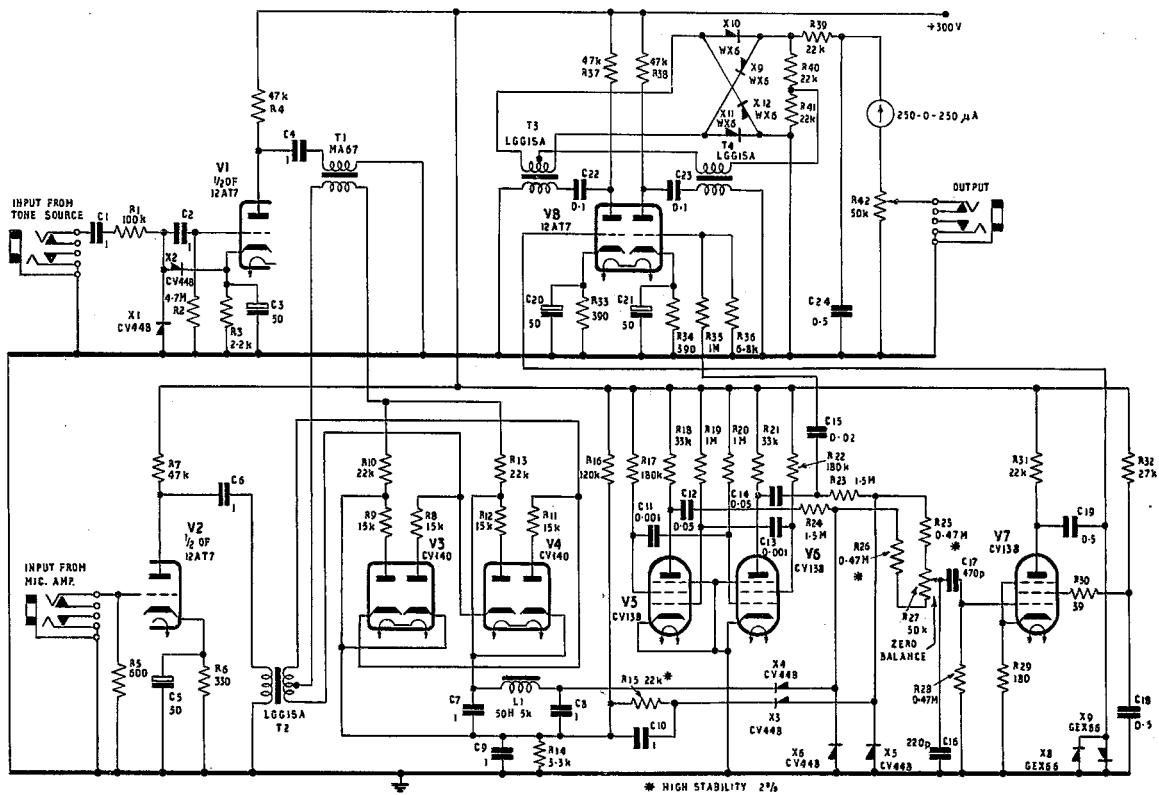


Fig. 2 - Coherent detector—circuit diagram

## 2.2. Description of the Instrument.

The complete circuit diagram is given in Fig. 2.

It will be seen that two inputs are provided, one for the returning signal and one for the high level tone direct from the tone source. This high level tone passes through a squaring circuit  $X_1$ ,  $X_2$ ,  $R_1$  and is then applied to an amplifying stage driving a ring modulator  $V_3$ ,  $V_4$ .

The microphone output, after amplification by a microphone amplifier, is applied to the grid of  $V_2$  and thence through the transformer  $T_2$  to the ring modulator. Thermionic diodes are used in the ring modulator because it is important to ensure complete stability of the rectifier characteristics. Series resistances were found to increase the efficiency of multiplication, the optimum value being 15k.

The output from the mixer is passed through a simple low-pass filter consisting of one  $\pi$ -section as shown. A more elaborate filter is not necessary, nor is it desirable, because of the possibility of ringing at the cut-off frequency. A small resistance in series with the inductance ensures that the filter is aperiodic.

Because of the fact that the output from the filter may contain frequencies down to D.C., logarithmic conversion presents some difficulties. The output from the filter is not sufficient to apply directly to a logarithmic element, so some form of amplification is necessary. Also, because of the subsequent logarithmic conversion,

"zero" stability in the D.C. amplifier is more than usually important. A modulation system is therefore employed, care being taken to preserve the sign of the output voltage during the logarithmic conversion and final de-modulation.

V5 and V6 constitute a screen-coupled multivibrator, from the anodes of which square waves are obtained. The operating frequency is 1000 c/s. The two antiphase outputs from the multivibrator are clipped by the diodes X3-6, and it will be seen that, in the absence of an output from the filter, the resulting signals are of equal magnitude. When these are combined in the network R25 R26 cancellation takes place and zero voltage is applied to the grid of V7. However, an output from the filter unbalances the system and square waves of amplitude proportional to the filter output are applied to the logarithmic amplifier V7. The phase of the square waves relative to the multivibrator depends on the sign of the output voltage from the filter. R15 compensates for the output impedance of the filter and mixer, and R27 is a zero balance control. R25 and R26 are of the high stability type in order to reduce to a minimum zero drift due to temperature changes in the instrument.

GEX 66 diodes are used as logarithmic elements and these provide a useful range of at least 50 dB. Because of other effects such as non-linearity in the mixers the operating range of the complete instrument is limited to about 40 dB. It is necessary to employ square waves in the logarithmic amplifier, since the demodulator responds to mean rather than peak values of input voltage. X9-12 constitute another ring modulator driven by V8. The switching waveform in this ring modulator is derived from the multivibrator, so the final output voltage is of the same sign as the filter output. Metal rectifiers are used in the second ring modulator as the stability of thermionic diodes is not necessary in this part of the circuit. A simple R-C filter (R39 C24) removes any remaining carrier voltage from the output, which passes through a gain control R42 to the output jack. An output of  $\pm 5V$  is obtained.

### 2.3. Details of the Experimental Method.

As shown in the block schematic diagram, Fig. 1, the normal pulsed glide chain is used, except that the octave filters and logarithmic amplifier are replaced by the coherent detector. The output from the coherent detector is applied directly to the triggered time-base cathode ray oscilloscope.

It was found quite early in the experimental work that it was essential to interchange the X and Y plates in the oscilloscope so that the time base sweep was perpendicular to the direction of motion of the film. If this was not done the patterns obtained were virtually unintelligible. Investigations were also made into the possibilities of normal pulsed glides with the oscilloscope plates interchanged in this manner, but here the disadvantages appeared to outweigh the advantages and the idea was not pursued further.

It was found that an optimum gain exists for the microphone amplifier driving the coherent detector. With excessive gain extraneous detail is liable to be recorded, while useful information may be lost if the gain is too low.

It was also found that, in general, it is desirable to include the maximum number of individual decays in the display, as this enables small formations to be identified more easily. A frequency range of 50 c/s to 500 c/s has been used in the

investigations, as above 500 c/s the change in frequency of the tone source during the period of a decay becomes significant. A glide rate of 8 minutes per octave was found to be suitable for most purposes. Tone source stability becomes a serious problem for slower glides than this and the time required becomes excessive.

### 3. EXPERIMENTAL WORK AND RESULTS.

The experimental work undertaken is divided into three main groups:

- (1) Coherent glides of rooms.
- (2) Coherent glides of electrical networks. This was undertaken in order to investigate the extent to which room behaviour can be simulated by electrical networks.
- (3) Methods involving auto- and cross-correlation.

#### 3.1. Investigations in Rooms.

Most of the experimental work was done in the Diesel House studio at Nightingale Square. This is an experimental talks studio with dimensions 15 ft 7½ in.  $\times$  12 ft 8 in.  $\times$  9 ft 6 in. (4.77  $\times$  3.86  $\times$  2.9 m) and a volume of 1880 cu.ft (54 m<sup>3</sup>). Table 1 gives a list of the frequencies of the axial modes for this studio.

TABLE 1

Table of Axial Modes up to 500 c/s for Experimental Talks Studio

c/s	c/s	c/s	c/s
36.2	144.6	267.5	397.7
44.6	178.3	289.2	401.2
59.5	178.3	297.3	416.3
72.2	180.8	312.0	433.9
89.1	216.9	325.3	445.8
108.4	223.0	356.7	470.0
118.9	237.8	356.8	475.9
133.7	258.1	361.6	490.5

A series of tests was undertaken to compare the coherent glide with the normal pulsed glide as a means of indicating the frequencies of subjective colourations. Early in the tests it was established that in order to obtain displays with which the colourations could be correlated, it was necessary to use a loudspeaker not very much larger than the human head, and an 8 in. unit in a closed-back cabinet of about 3 cu.ft capacity was adopted. Subjective tests showed the principal colourations to be at 90, 140, 175 and 220 c/s and it will be seen from the table that these correspond to isolated axial room modes or groups of modes. Six coherent displays, from different microphone positions, and five normal pulsed glide displays were examined by three observers and the frequencies of indicated singularities were listed. Corresponding

formations of the types associated with strong isolated modes are visible in Figs. 3 and 4. The straight line formation of the normal pulsed glide appears at (a) in Fig. 3, while at (b) in Fig. 4 is the corresponding pattern obtained by the coherent detection method. The general slope of the decays in the latter is the cause of the noticeable asymmetry of the pattern, and this would be reversed if the microphone leads were interchanged.

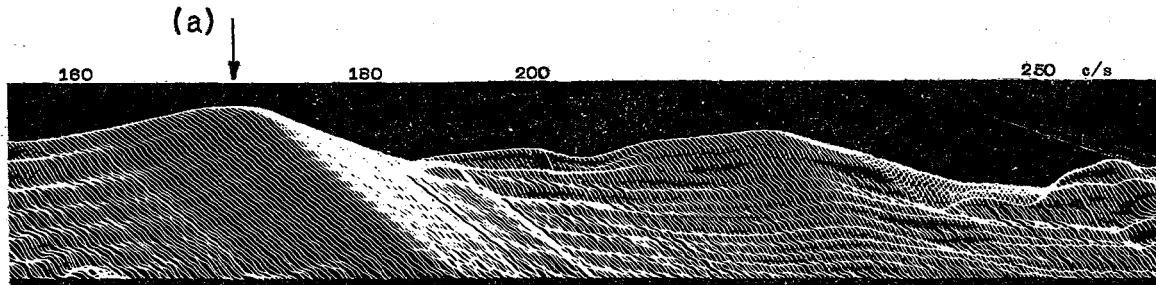


Fig. 3 - Part of a normal pulsed glide of a small room

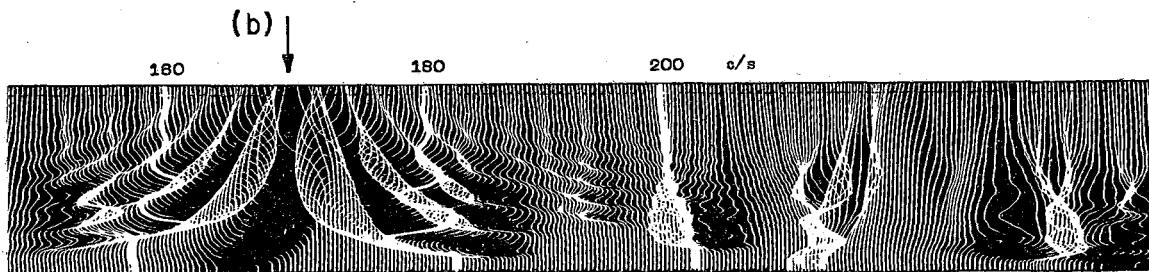


Fig. 4 - Part of the phase coherent pulsed glide corresponding to Fig. 3

The results of these tests may be summarised as follows:

(i) Normal Pulsed Glide

This showed severe colourations at 137, 160 and 225 c/s with a minor group at 150 c/s.

(ii) Coherent Display

The most severe formations shown were in the range 215-225 c/s, other sharply localised groups being at 88-98 c/s, 140-150 c/s and 320 c/s. There was also a diffuse group ranging from 180 c/s to 200 c/s.

Thus the normal display showed two of the subjectively important colourations and two spurious frequencies; the coherent display showed three of the known colourations with two spurious groups. It may be remarked that the coherent display showed the very important colourations at nearly all microphone positions, whereas the conventional display was less uniform in this respect.

The coherent display, therefore, appears to be slightly better as a means of diagnosis, although it shares the disadvantages that several microphone positions are necessary and that spurious indications are normally present as well as correct ones.

An examination of a typical coherent glide shows that simple, clear patterns are only rarely obtained. Most of the formations present are of a random nature, probably due to reflections taking place before standing wave systems can be built up. These effects tend to obscure any regular patterns by covering them up in the display.

It will be noticed that compression or bunching of the commencement of the traces occurs at intervals along the display. This is due to the progressive phase advancement with frequency which takes place with a fixed microphone and loudspeaker spacing. (See Section 3.3 below.) Patterns characterised by a beat frequency which is constant and independent of the tone source frequency over a region of several cycles may also be observed occasionally in the display. These beats probably take place in the room itself, between adjacent modes, and are not a result of the modulation process in the coherent detector.

Fig. 5 is part of a coherent glide taken in a large studio (Maida Vale Studio No. 1). It will be seen that successive decays differ too much for any patterns to be visible. This is because the response of the studio changes very rapidly with frequency. In addition the frequency change between successive pulses is larger than usual because of the longer reverberation time of the studio. It is clear from these considerations that useful patterns are formed only in small studios, where the response changes relatively slowly with frequency.

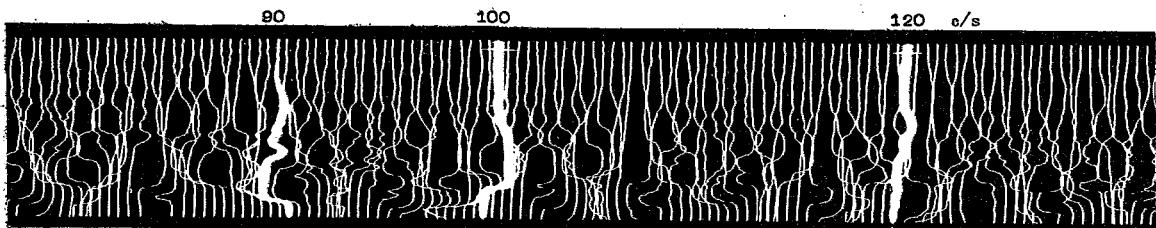


Fig. 5 - Part of a phase coherent pulsed glide taken in a large studio (Maida Vale 1)

### 3.2. Some Theoretical Considerations in Connection with Small Rooms.

Compared with the conventional pulsed glide, the coherent type of display possesses a slightly superior resolving power. This is illustrated by one particular case in which a region only a few cycles wide was shown by the coherent display to contain two very closely spaced modes. The region appeared on a conventional pulsed glide simply as a series of smoothly rounded decays.

The improved resolution is largely due to the fact that there is a visible change of phase as a room mode is passed through. It will be appreciated that, in a display which is sensitive only to amplitude, a spacing of 2 c/s or less between modes will not be observable unless the reverberation time is appreciably greater than

0.25 seconds. Even when this condition is satisfied, it is necessary to ensure that the frequency change between pulses is not greater than 1 c/s if it is desired to preserve this detailed information. This remark applies, of course, equally to both types of display. It should be noted that since data concerning normal modes is, in general, most useful in connection with colourations in small talk studios, and as these rarely have reverberation times in excess of 0.4 seconds, the coherent type of display possesses an intrinsic advantage in this application.

### 3.3. Coherent Glides of Electrical Networks.

In order to obtain a better understanding of coherent glide displays from rooms, it was decided to investigate the displays obtained from certain simple networks, such as tuned circuits. The essentially resonant nature of room modes suggested that patterns might be obtained from tuned circuits similar to those obtained from strong isolated modes. This was in fact shown to be the case.

Coherent pulsed glides were taken of the following networks:

- (a) Single tuned circuit.  $Q = 50$ ,  $f_r = 250$  c/s approx.
- (b) Two tuned circuits, uncoupled and with various spacings between frequencies of resonance.  $Q = 50$ ,  $f_r = 250$  c/s approx.
- (c) All-pass network.

The response of the coherent detector to a single tuned circuit was also calculated and the results compared with those obtained in practice. To facilitate the comparison of individual decays, the spacing between the decays was increased in two of the glides. The glides of the single tuned circuit are shown in Figs. 6, 7, and 8, and some of the computed curves are given in Fig. 9.

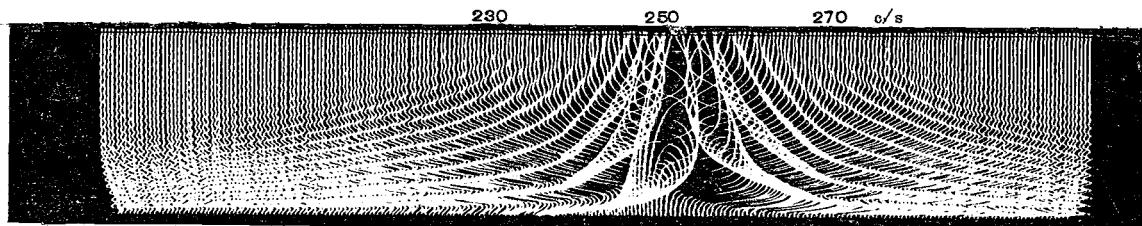


Fig. 6 - The pattern produced by a phase coherent pulsed glide of a tuned circuit

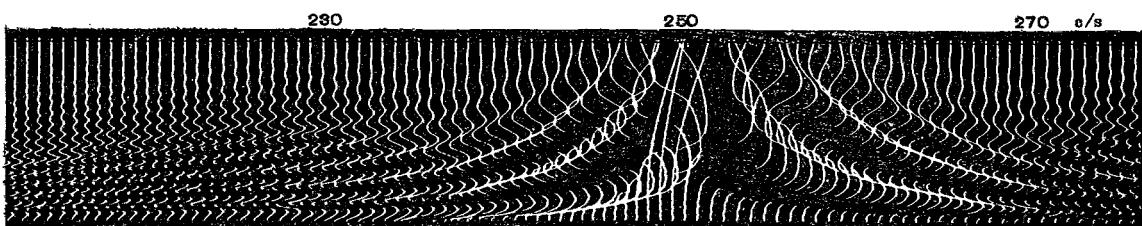


Fig. 7 - The pattern produced by the tuned circuit of Fig. 6, with the frequency scale expanded

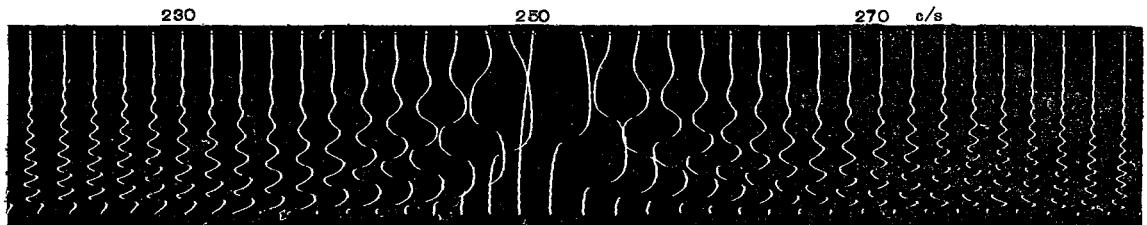


Fig. 8 - As Fig. 7, but with the pulsing rate reduced to enable individual traces to be seen

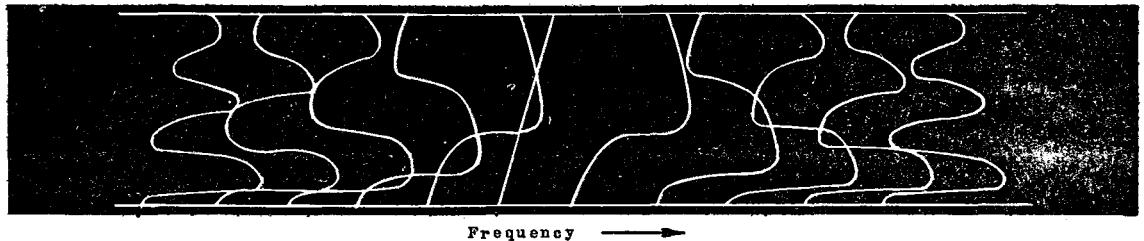


Fig. 9 - Computed curves for the single tuned circuit, for comparison with Fig. 8

Figs. 10 and 11 show the response of the coherent detector to the two tuned circuits (see (b) above), with resonance separations of 10 c/s and 2.5 c/s. The glide rate of the tone source was specially reduced in this case, to lessen the complexity of the patterns produced. It will be seen by comparison with Fig. 6 that resonance separations of 2-3 c/s are resolvable.

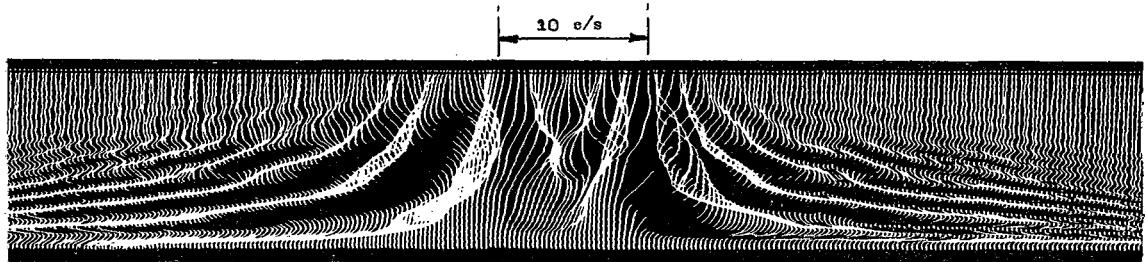


Fig. 10 - Part of a phase coherent pulsed glide of two tuned circuits, uncoupled, and with a resonance frequency separation of 10 c/s

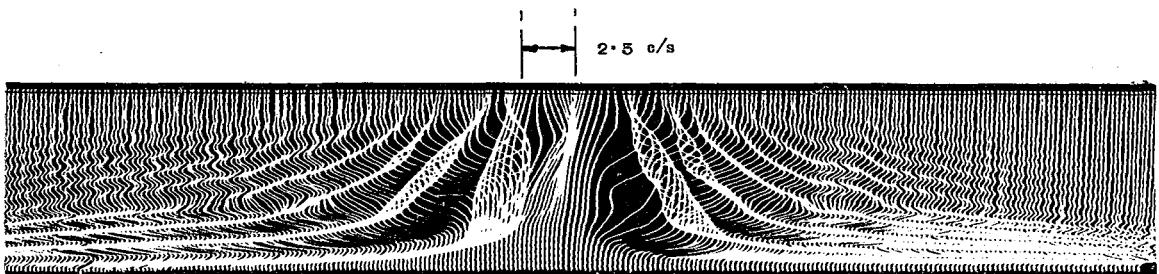


Fig. 11 - Part of a phase coherent pulsed glide of two tuned circuits, uncoupled, and with a resonance frequency separation of 2.5 c/s

Part of a "glide" of the all-pass network shown in Fig. 12 is given in Fig. 14. It illustrates the bunching and expansion of the decays which results from a phase characteristic  $\phi(\omega)$  of the form

$$\phi(\omega) = 2N \tan^{-1} k \frac{\omega}{\omega_r} \left[ 1 - \frac{\omega^2}{\omega_r^2} \right]^{-1}$$

where  $N$  is the number of sections of the network

$k$  is a circuit parameter

$\omega_r$  is the frequency at which  $\phi = N\pi$

A similar effect of dispersion is observable in all coherent glides of rooms; it appears as a background to the more striking patterns due to eigentones and strong early reflexions.

A careful examination of coherent displays from small rooms shows that, for rooms having reverberation times of less than about 0.4 seconds, most of the patterns obtained are due to early reflections, the real eigentone regime in many cases never being reached. Thus, the characteristic resonance patterns of Fig. 6 are rarely found in an easily identifiable form in displays from rooms, and when they do appear they generally indicate modes which are both undamped and also sufficiently isolated to prevent their being covered up, in the display, by neighbouring formations. From these considerations it would appear that early reflections may play an important part in determining the quality of speech from a typical small talks studio. Unfortunately, these effects depend almost entirely upon microphone position and so the assessment of the overall "goodness" of a studio from instrumental measurements or displays becomes a difficult problem once its major acoustical faults have been removed.

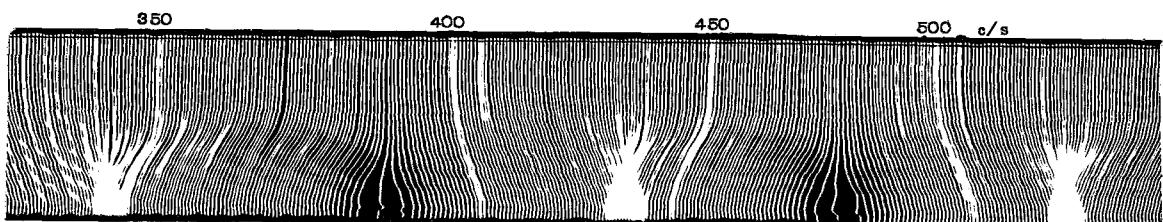
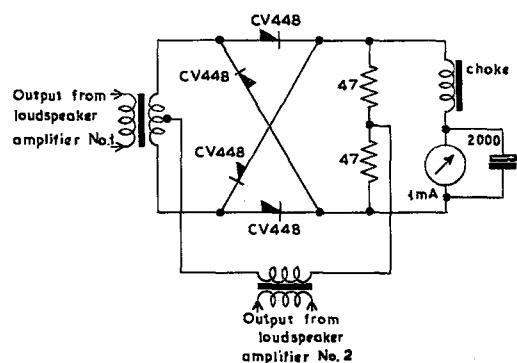
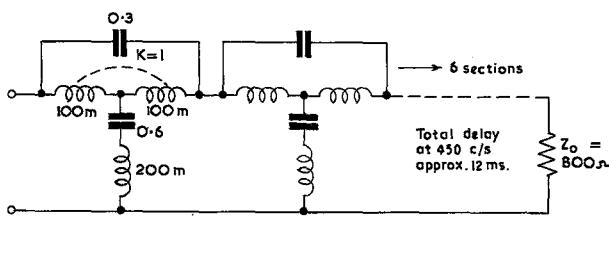


Fig. 14 - Part of the phase coherent display of the network illustrated in Fig. 12, showing effects of periodic phase reversal

## 4. METHODS INVOLVING AUTO- AND CROSS-CORRELATION.

A study of methods involving correlation was made in an attempt to measure properties that are characteristic of the studio as a whole, rather than of particular microphone positions. As mentioned in the previous section, this is one of the fundamental difficulties in acoustical measurement, and correlation methods would appear to be very advantageous in this respect.

Gershman<sup>3</sup> has used correlation methods in an attempt to measure a quantity corresponding to the liveness of a room.

If  $v(t)$  is the instantaneous sound pressure at time  $t$  at a point in the room, and  $\tau$  any arbitrary time interval, the autocorrelation function of  $v(t)$  may be written in its simplest form as

$$\psi(\tau) = \lim_{T \rightarrow \infty} \frac{1}{2T} \int_{-T}^{+T} v(t)v(t+\tau)dt$$

Parseval's theorem<sup>4</sup> states that if  $f_1(\omega)$ ,  $f_2(\omega)$  are the Fourier transforms of  $\phi_1(t)$ ,  $\phi_2(t)$ , and if \* indicates the conjugate of a function of a complex variable,

$$\frac{1}{2\pi} \int_{-\infty}^{+\infty} \phi_1(t)\phi_2(t)dt = \int_{-\infty}^{+\infty} f_1^*(\omega)f_2(\omega)d\omega = \int_{-\infty}^{+\infty} f_1(\omega)f_2^*(\omega)d\omega$$

Writing  $f(\omega, t)$  as the Fourier transform of  $v(t)$  we see that  $f(\omega, t)e^{i\omega\tau}$  is the transform of  $v(t+\tau)$  and hence the autocorrelation function may be written

$$\int_{-\infty}^{+\infty} \lim_{T \rightarrow \infty} \frac{\pi}{T} |f(\omega, T)|^2 e^{i\omega\tau} d\omega,$$

since the function  $f(\omega, T)$  is real and equal therefore to its conjugate.

Since  $|f(\omega, T)|^2$  is an even function of  $\omega$ ,

$$\psi(\tau) = \int_0^{\infty} \lim_{T \rightarrow \infty} \frac{2\pi}{T} |f(\omega, T)|^2 \cos \omega\tau d\omega$$

We may write,

$$F(\omega) = \lim_{T \rightarrow \infty} \frac{2\pi}{T} |f(\omega, T)|^2$$

where  $F(\omega)$  is the spectrum power function, i.e. the energy density at frequency  $\omega/2\pi$  and hence  $\psi(\tau)$  is given by

$$\int_0^{\infty} F(\omega) \cos \omega\tau d\omega$$

Gershman expresses this in a normalised form

$$R(\tau) = \frac{1}{V^2} \int_0^{\infty} F(\omega) \cos \omega\tau d\omega$$

(where  $V$  is the RMS amplitude),

and shows that in general, the function falls substantially to zero after an interval  $\tau_0$  which he defines as the "coherence interval".

He prefers to express this interval as the distance  $c\tau_0$  travelled by the sound from the source. For pure tone  $c\tau_0$  is infinite, but a band of noise of finite width gives a finite correlation interval which decreases as the bandwidth increases. Thus, an octave band of noise from 800 c/s to 1600 c/s has a coherence interval of about 70 cm, and the band from 3,200 c/s to 5,400 c/s only about 18 cm. Outside these distances any observed correlation between the signal from a microphone and the exciting signal from the loudspeaker must be due to standing wave effects, and any cross-correlation observed between two microphones at a similar distance apart must be due to standing wave effects or symmetry with respect to the source.

If  $v(t)$ ,  $u(t)$  are the two microphone signals in the latter case, the cross-correlation between them may be expressed most generally as

$$\lim_{T \rightarrow \infty} \frac{1}{2T} \int_{-T}^{+T} v(t)u(t+\tau)dt$$

The effect of varying  $\tau$  is not significant for the present purpose and therefore Gershman makes  $\tau = 0$ , giving

$$\lim_{T \rightarrow \infty} \frac{1}{2T} \int_{-T}^{+T} v(t)u(t)dt$$

which is simply the time-averaged product of the two instantaneous signals. He shows that in the case of two microphones placed symmetrically about the axis of a loudspeaker, this function is a useful measure of the liveness of a room.

It will be seen from this that Gershman uses the departure from complete correlation in a symmetrical case to indicate a phenomenon viz. liveness, due to reflections from the walls of the enclosure. If, instead, the symmetry is eliminated and the distances between the transducers are all made greater than the coherence interval, there will be zero correlation unless there are appreciable standing wave effects at both positions, since standing wave systems have only two (opposite) values of phase throughout the room.

#### 4.1. Cross-correlation Methods.

This approach has been followed in some experiments performed in the two experimental talk studios at Nightingale Square<sup>5</sup>. The circuit used for performing the cross-correlation consisted of a ring modulator fed with the two microphone signals, each of which was adjusted independently to a known fixed value. This adjustment having been made, the output from the modulator gave the correlation coefficient. A diagram of the circuit is given in Fig. 18. Uncorrelated inputs from two noise generators give a coefficient of less than 0.1 by this method, and this figure was taken as the threshold of accuracy of the method. Microphones were placed at two points in the room, and a loudspeaker was fed with a band of noise wide enough to put both microphones outside the coherence interval with respect to each other and the loudspeaker. A difficulty arises here, however, since the coherence interval for a talk studio of normal size may be greater than the room dimensions except for bands

of noise wide enough to excite many modes. Each standing wave system will give either +1 or -1 correlation between two microphones, and hence the coefficient for the band may have any value between -1 and +1, depending upon the number and sense of the separate correlations within the band. In the actual experiments two pressure microphones were placed in each of the 12 pairs of corners having diagonal relationships to each other (i.e. two or three co-ordinates different), the loudspeaker being in another corner. For each pair the correlation coefficients were read for octave bands of noise with central frequencies ranging from 120 c/s to 1700 c/s. The mean of the moduli of the 12 figures for each band would be a measure of the importance of the standing wave effects in the band.

The results were as follows:

TABLE 2

Mean Cross-correlation Coefficients between Pairs of Microphones in a Studio

Mid-frequency	120	240	480	950	1700	c/s
Studio No. 1	0.26	0.21	0.12	0.11	0.05	
Studio No. 2	0.27	0.25	0.10	0.10	0.08	

The differences between the two studios are thus quite insignificant, and it is concluded that the figures obtained are a function more of the method than of the studio.

#### 4.2. Coherent Glide between Two Points in a Studio.

Another possible method of obtaining a synthesis of two microphone positions is to use a modified form of the coherent detection display described in Section 2. The normal coherent detection equipment is used but the tone input to the modulator is replaced by a signal from a second microphone, the output of which has been amplified and squared. This method gives a simpler display than the single-microphone method previously described, because the beats of continuously varying frequency which form a prominent feature of the latter, are absent.

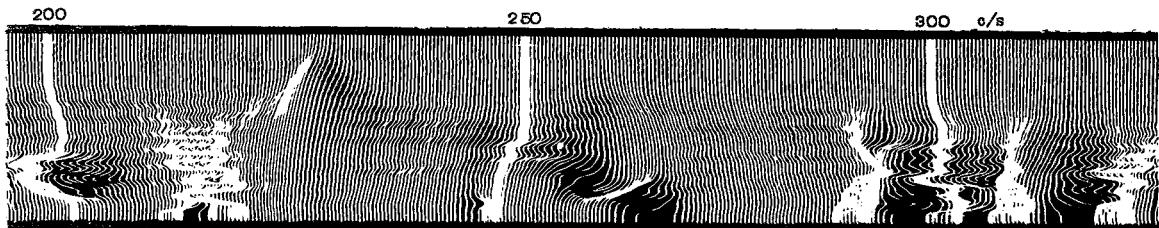


Fig. 15 - Part of a cross-correlated coherent pulsed glide taken in a small room

Fig. 15 shows part of one such display, using microphones in two corners of a small room. It will be seen that the display consists mainly of comparatively unmodulated decays interspersed with regions where the decays show beats of constant frequency over an appreciable range of exciting frequency. Each of the two microphones, being in a corner of the room, will be excited at all modal frequencies, and

at any particular exciting frequency the modes most strongly excited will be those adjacent in frequency above and below. Hence the display will tend to consist of straight lines at or around the modal frequencies, while at frequencies approximately midway between them, there will be strong beats. The substitution of a signal from the room for the tone used in the ordinary coherent display causes the disappearance of the beats of continuously varying frequency which is a feature of the frequency region surrounding isolated eigentones in the ordinary display. This method therefore has possibilities as a means of exploring the distribution of particular room modes but the possibilities have not yet been exploited.

## 5. CONCLUSIONS.

A method of exhibiting the phase relationship of reverberant sound in a room with respect to the exciting tone has been developed. The resulting displays show no great advantage as a method of diagnosis over the conventional amplitude pulsed glide previously described, having the same basic limitations. The method does, however, permit a more detailed analysis of particular frequency ranges to be made, since because of its sensitivity to phase as well as amplitude, it possesses a slightly higher resolving power. Its most useful application is in connexion with colourations in small talk studios; it is less useful than the conventional pulsed glide for larger enclosures.

Cross-correlation methods do not appear to be very useful in normal circumstances, although the cross-correlated coherent glide may have some application in the investigation of the spatial distribution of particular room modes.

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